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TECTONIC TRANSPORTS IN THE CALEDONIDES
OF NORTHERN SCANDINAVIA EAST AND SOUTH
OF THE ROMBAK—SJANGELI WINDOW

BY

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LUND
C.W.K. GLEERUP

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HÅKAN OHLSSONS BOKTRYCKERI

1958

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In this thesis, two papers of mine are summarized, wherein I have tried to find out phases of tectonic deformation, directions of transport, and some other deformation characteristics, in part of the northern Caledonides of Sweden. In the following text, these two papers will be referred to only by their publication years, thus, (1957), and (1958).

I began the series of work that has led to this summary, without any working hypothesis. It was my purpose to find out, what complications that do really exist in a complex of overthrust metamorphics that I had for a few summers assisted in mapping on the scale 1:100 000, and why, apart from inexperience, it was so difficult to correlate the beds with one another from section to section. The geological field map on 1:10 000 that resulted from my work in the mica-schists and marbles of the Pålnoviken area was hard to understand without knowledge of macroscopic fabric, so I spent another season collecting about 2000 fabric data, and mapping some structures on 1:1000 and 1:2000. I tried, like some previous workers, but not with as much success, to find mechanic principles whereby all, or most of the structures could be regarded as due to one sequence of deformations, with one direction of main regional transport. However, when all the axial structures were brought together in synopsis, it appeared that there was, rather evenly distributed in the area, not one, but several populations of axes with regard to direction (LINDSTRÖM 1955, p. 6). Six populations were distinguished then. Even with a very cautious interpretation, one must distinguish four. If each phase of deformation can give rise to two populations of axes, one parallel and one at right angles to the main transport, this meant to me that there was evidence of three phases of deformation in that area. The hypothesis that these phases were of more than local importance must then be checked by work in a chain of other areas along the strike of the Caledonides. On the further hypothesis that the transport direction of a given phase might diverge from one area to another, the areas were chosen so as not to be too far from one another. The hypothesis that folds could be formed parallel to the transport had to be specially checked. My ideas of the relative ages of the deformation phases had to be changed as somewhat less crude methods of age-determination were devised. Thus, I have changed methods and hypotheses in the course of the studies, and shall probably continue to do so. For this reason, I do not like to formulate a morale of the story of the work, as I can tell it now. However, one great difference between a good story of fiction and an average scientific publication, is that whereas the former can be entertaining and perhaps even useful without the

author's pointing out what we are to learn from it, it may occasionally be necessary for the scientific author who wants to make a contribution to general knowledge, to snatch from the readers the privilege of forming a conclusion. So, at the end of this thesis, I have suggested some more general hypotheses that can be founded on this work. They may be disproved by future studies, but I believe that they are not disproved by anything that has so far been published.

The Caledonian metamorphics in the areas with which we are concerned form a vast, comparatively thin, nearly horizontal sheet on a basement that seems to be largely of pre-Cambrian crystalline rocks. The tectonic transport in general was parallel to this almost horizontal sheet. Thus, transports of all phases have, roughly speaking, had one plane in common, a condition that simplifies tectonic work a great deal.

Geologic research in the Scandinavian Caledonides has largely been focussed on the questions, whether there was any large-scale thrusting, how the overthrust complex should be correctly subdivided on tectonic, stratigraphic, and petrologic principles, what ages are to be assigned to the various overthrust rocks, and through what stages the rocks got their present lithologic characteristics. Only the first of these questions is of the utmost importance in this study. By now, there is conclusive proof for large-scale thrusting, so that the question has ceased to be debated. See, i.a., the following works, ASKLUND 1938, HOLTEDAHL 1953, pp. 262—454, G. KAUTSKY 1953, KULLING 1953, 1955, MARKLUND 1949, STØRMER 1933.

Comparatively little space in literature has been given to the questions of the sequence of deformations. There are some trends of thought, but not much discussion. A. G. HÖGBOM (1909, p. 340) suggested that there was first a very large-scale thrusting toward SE, then, in the NW parts of the metamorphic complex, there was a phase of strong folding. HOLTEDAHL (1938, p. 28) suggests that flexures were formed in the basement after thrusting. HÖGBOM's hypothesis of folding after thrusting reappears with F. KAUTSKY 1940, p. 137, and F. KAUTSKY & TEGENGREN 1952, pp. 460—464, and is elaborated by G. KAUTSKY (1946). According to him, the overthrust nappes were transported at least 250—300 kilometres toward SE before plastic folding and granite reactivation began in NW, with transport partly toward NW.

On the other hand, HOLTEDAHL (1931, p. 275) and FØYN (1937, p. 155) suggest that overthrusting (toward SE) was later than folding (on NNE axes) in areas in the extreme north of Norway.

BACKLUND (1935, p. 431) mentioned early (Taconic?) movements toward ESE and later [Erian? (=Ardennian, cf. STILLE 1950, p. 227)] movement toward SE, for the Västerbotten part of the Swedish Caledonides. For part of the same areas, DU RIETZ (1943, p. 8) concluded that there was first transport toward SSE (folds striking ENE), then, during the main overthrusting [Erian (=Ardennian, STILLE 1950)], toward ESE (fold axes in N10°E).

Fold structures and so-called stretching (e.g. elongation of conglomerate pebbles) at right angles to the strike of the mountain chain have attracted much justified

attention. REUSCH (1888, pp. 15?, 16, 175) gave the first, and probably also the best, figures and descriptions of these phenomena. The interest in the "stretching" and "cross-folds" grew as the hypothesis of great overthrusting toward ESE became the central topic of discussion, after the publication of TÖRNEBOHM's 1888 paper. WERENSKIÖLD (1911, p. 35) gives a considerable list of these structures.

The most important question is, if the "cross-folds", or transverse folds, were formed at the same time as the folds striking NE-SW (longitudinal, or Caledonoid, folds), or not. In this connection, it is essential that most authors have to some extent homologized the "stretching" with the transverse folds, so these phenomena need not be held apart for the present. Among others, HOLMQUIST (i.a. 1900, pp. 72-102) and KULLING (1930, e.g., p. 672) regard transverse structures as a result of movement along the Caledonoid strike, separate in time from the main NW-SE movements.

According to i.a. TÖRNEBOHM (1896, pp. 125, 126) and KULLING (1933, pp. 220, 389) certain transverse folds were formed later than Caledonoid folds. BJØRLYKKE (1905, pp. 593, 594) and DIETRICHSON (1953, p. 66) regard transverse folds as older than the Caledonoid ones.

Contrary to these, quite a number of authors have regarded the transverse and Caledonoid axes as largely contemporary, or at least as due to movements in the same direction, viz. ESE-SE. See, i.a., HAMBERG 1910, p. 716, FRÖDIN 1921, p. 183, A. HÖGBOM 1925, p. 23, STRAND 1938, p. 69, VOGT 1945a, p. 121, MARKLUND 1949, p. 217, LANDMARK 1949, 1951, ALEVA 1950, p. 30, G. KAUTSKY 1953, p. 223, DIETRICHSON 1957, p. 11.

VOGT (1927, pp. 91, 104) described hypothetical mechanisms whereby linear structures could arise at oblique angles to the main tectonic transport.

The introduction of graphical-statistical methods and of the tectonic symmetry coordinates of SANDER brought about certain changes in tectonic thinking in Scandinavia. Diagrams for several fabric elements, founded on a good number of strike readings, were published already before that, by VOGT (1927, p. 127). The transverse axes, being most probably parallel to the main tectonic transport, were identified with the tectonic α -axis of SANDER by several authors, i.a. CLOOS 1946, p. 26, KULLING 1955, pp. 276, 296, PADGET 1955, p. 99. Special fabric studies were devoted to the transverse linear structures by STRAND (1945), KVALE (i.a. 1945, 1948, 1953), and OFTEDAHL (1948). These authors also regard the transverse axes as parallel to the main transport.

KVALE, on finding several divergent sets of linear elements, or lineations, in the Bergsdalen area in the Caledonides of western Norway, formulated the alternatives (1948, p. 7, 1953, p. 57). Either there were several ("at least six") directions of transport, or a lineation could be formed at almost any angle to a tectonic transport. He found the second alternative to be the most probable. In STRÖMBERG 1955, p. 239, and LINDSTRÖM 1955 & 1956, KVALE's first alternative is tried instead. My papers 1957 & 1958, and this summarizing thesis, present a continuation of these studies.

My observations have been done in six small areas, situated, with intervals of 14—22 km, along an 85 km long line that runs in a SSW direction from the NW end of the lake Torneträsk (approximately Lat. $68^{\circ}28'$, Long. $18^{\circ}36'$) to the SE end of the lake Sitasjaure (about Lat. $67^{\circ}50'$, Long. $17^{\circ}39'$). From north to south, the areas are called the Pålnoviken area, the Nuolja area, the Kartimvare area, the Allesjaure area, the Haukajaure area, and the Sitasluspen area. Much of these areas is 800 metres and more above sea-level, little is lower than 600 metres. Torneträsk can be reached by railway, for the rest, one has to walk.

The areas are situated east and south of the Rombak—Sjangeli window that is a big dome-shaped exposure of the crystalline (probably) pre-Cambrian basement over which the Caledonian nappe complex was thrust. No exact observations were done by me on these rocks. I do not believe that they were very much affected by the thrusting, except in the very contact zone. The crystalline rocks are covered in patches by relatively un-altered sediments, including a basal conglomerate and phyllites. Though they are regarded as part of the basement, they were partly investigated in the Haukajaure area. The "hard-schists" that follow above the basement in all the areas are clearly overthrust. They are extremely fine-grained and largely quartzitic, although with gneissic beds and some dolomitic inclusions. Their thickness varies. They are marked by completely penetrative lineations. Above these schists there is a calcite marble complex that may be very thick but may also be reduced to a thin smear. In the boundary zone between this complex and the hard-schists, there may be shreds of amphibolite. In the Kartimvare area, there is only amphibolite above the hard-schists, and no marble complex. Otherwise, the marble is followed upwards by light-grey phyllitic garnetiferous mica-schists, the highest tectonic member studied.

In each of the areas about 50 localities were investigated. At each locality, the orientations of about 13—14 s-surfaces were recorded as exactly as possible, together with lineations occurring on them. The lineations were either minor folds, or bands and striae on s-surfaces, or, very frequently, intermediates between the first two kinds. The categories could not be held apart. Whenever a fold lineation was clearly overturned in some direction, this direction was recorded. Where the age-relationships of intersecting lineations was obvious, this was also recorded. Little attention was given to joints.

The SCHMIDT net was used for the indoors work. A β diagram, including all s-surface intersections, was constructed for every locality. As the s-surfaces often diverge but little, a special technique had to be used for this (1958, p. 8). Then, all β from the locality diagrams of tectonic units, sub-areas, and whole areas were brought together into total diagrams. Such diagrams were also prepared for the lineations. On the whole, a higher degree of significance is attributed to the maxima of concentration of the total diagrams than to those of locality diagrams.

Different methods were used in order to ascertain the age-relationships of the axes. The determinations of relative ages of lineations done in the field were brought together in one or two synoptic diagrams for each of the areas. This straightforward

method may give one a good idea of the general directions of older and younger axes. Two other methods are based on the relationships between lineation and s-surface orientations. If there is a very penetrative lineation fabric and almost parallel, but broadly and smoothly undulating s-surfaces, the undulations of the s-surfaces are not likely to be older than the lineations. If the axis of the undulations diverges from the direction of the lineations, the undulations should be the younger. This relation was noted for all localities, where it was obvious, and a synopsis of the cases was prepared for each area. On the other hand, it happens that lineations occur on s-surfaces that, far from being gently warped, are folded and dip steeply. If the fold axis is horizontal but the lineation is not, the lineation may have been rotated about the fold axis and thus brought into its present position. If this is the case, the lineation is older than the fold axis. It is not true that this relation holds in all cases of lineations on fold flanks, but it is probably true in the majority of the cases in these areas, although it cannot be proved in each case. Here is thus another method of age-determination that is best used in synopsis. For the fourth, and last, method of determining the relative ages of the chief axial directions, I assume that the s-surfaces that diverge the most in orientation from the mean of their localities were brought into position by relatively late rotation. Such s-surfaces determine the local β concentrations more than others. If their influence is reduced, the β of the earlier deformations should appear the better. To make the earlier β appear, a total diagram was prepared for each area, employing only the β of adjacent s-surfaces, so that each s-surface only yielded two β , one with the surface next before, and one with that next after in the field notes (and thus in the field as well).

These methods have been elaborated as my tectonic studies proceeded, and were not, or only very little used in LINDSTRÖM 1955 & 1956. Some conclusions on the relative ages of deformations that were reached in those two papers can therefore not be defended. However, the material collected for them has been revised with the methods later adopted, and the results are used here.

In order to determine the relative ages of the very important transverse fold axes, one must know if they were indeed formed parallel to a direction of main transport, thus representing $B' = a$. The symmetry of the individual lineation as a rule is monoclinic, with the symmetry plane, ac , at right angles to the lineation. If Caledonoid fold lineations (strike NE—SW) are regarded together, the monoclinic symmetry still prevails. Practically all of them are overturned in the same direction, toward SE. This was also the direction of transport. If, on the other hand, all transverse lineations of a certain strike trend are summarized, there does not appear any constant sense of overturning. The local monoclinic symmetry is not the symmetry of the total. Not only can the folds be overturned in any direction: the axial planes can make any angle with the horizontal. There are localities with a predominant transverse lineation where a great number of axial plane orientations are realized. The resulting deformation planes may look much like coloured fluids mixed by stirring. The ideal symmetry of the total of transverse lineations with a

certain direction trend is therefore axial, although local, or possibly even regional symmetry may be monoclinic. Main transport therefore must have been parallel to the transverse lineations. If this was so, and the lineation folds merely were formed by local, minor, transport of adjustment normal to the main transport, then the transverse folds would have a permanence that could not, particularly in a very intensive main transport under high hydrostatic pressure, be expected for folds normal to the main transport.

As quartz *c*-axes tend to fall in the tectonic *ac* plane (cf., e.g., SANDER 1950, pp. 143—145, & D48—D53, p. 364), it was natural at an early stage to check the assumption that the transverse lineations are parallel to a chief transport direction, *a*, by making quartz fabric diagrams for samples with transverse lineations. The quartz *c* maxima might then strike in the same directions as the lineations. Quite on the contrary, it was found that in the five cases investigated (1957, p. 10, & D4—D8, pp. 29, 30), the quartz axes tended to strike at right angles to the lineations. I am not trying to explain this on mineralogical grounds. However, if there really was a transport in the direction indicated by the quartz *c* axes, and the lineations are thus normal to this transport, then this transport must be regarded as subordinate to the transport parallel to the lineations. Possibly, the reason why the quartz fabric came to be determined by the subordinate, and not by the main transport could be that the main transport, which on the whole was rectilinear, took place largely in the more micaceous *s*-surfaces, and left the quartzitic microlamellae comparatively unaffected, whereas the minor transport in $a'=b$, which was manifestly turbulent, affected quartzitic and micaceous components alike, and came to determine the quartz fabric. If so, the crystallographic orientation of mica should reflect the direction of main transport. Due to the exceedingly fine grain of the mica, this has so far seemed impossible for me to find out.

Where the crystalline basement rises to some height, the tectonic units next above it get thinner and disappear, and the top of the basement shows evidence of strong deformation. This is interpreted as evidence that the elevation of the basement existed, at least in part, already before the discernible phases of deformation.

Most exceptions to the rule that Caledonoid folds are overturned toward SE are found in the Haukajaure area. Some Caledonoid folds tend to be of axial symmetry (1958, p. 44). They occur on the W side of a ridge of basement that may have stopped up the movement toward SE in the lower part of the nappe complex and forced the material to flow around it. With the direction of local main transport, the accompanying structures became deflected as well.

On the same, W, side of the said ridge, phyllites of the basement have acquired Caledonoid fold structures that tend to be orthorhombic (1958, p. 44), with overturning both toward SE and NW. There seems thus to have been considerable squeezing, but little possibility of escape for these phyllites.

East of the ridge, the basement phyllites contain folds that also tend to be overturned toward NW (1958, p. 46). They are slip folds, and, if interpreted according to W. SCHMIDT (1932, p. 83), must be due to transport toward SE. Even with the

fold slip theory of KIENOW (1949, pp. 369—371), the distribution of slip planes relative to the limbs of major folds will prove that there was transport toward SE. It seems that overturning toward NW occurs wherever in this series one finds evidence of "slip folding".

It has been inferred that rotation of the maximum and minimum stresses occurred on the lea (SE) side of the resistant structures. Thus, some structures, i.e. boudinage, that arose in such places are oriented in such a fashion as first to suggest transport from SE. In a transport from SE they would, however, have been too unstable to persist.

In the following, transverse axes are regarded as tending to be parallel with, and indicating the directions of main transport.

Within the realm of a rock chip, a locality, a tectonic unit, or an area, there are different tectonic axes. The importance of the trend of such an axis is proved as it is found in more and more comprehensive units. The relative ages of the axial trends found in an area could be found out with the methods already mentioned. The phases of deformation distinguished by their respective axial trends were given provisional names from typical localities found in mappable tectonic connection in the Pålnoviken area, (1957, p. 23). In the Pålnoviken and Nuolja areas, there could possibly be some evidence of a very early deformation, with axes about N—S and W—E. This phase could not be given a name, as there is not any typical evidence. The earliest characteristic phase is the most penetrative *Påloluokta phase*, with transport toward SE and ESE. During what seems to be the earliest stages of this phase, transport was toward S37°—51°E (1958, p. 61). The hard-schists, in particular, got their most important set of lineations, striking N47°—50°W, absent only in the Haukajaure area. During later stages, there was transport toward S54°—77°E. Of the main transport trends, one toward about S75°E was probably earlier than one toward about S62°E (1958, p. 61). It may be that there was some even younger transport toward about S50°E (1958, p. 62, the difficulty of determining the age-relation of the β maximum of the Nuolja area and the hard-schist lineations relative to axes about N64°W could be due to such a stage, cf. 1957, p. 19, & 1958, p. 60).

What has been called the *Trappsteget phase* came next in time. Transport was toward about S18°E and S35°E. It is possible that the former direction was the earlier (1958, p. 62). This direction appears, on the whole, to be better represented by lineations than by β , and it is also better represented in selective than in ordinary β diagrams. For the three northerly areas it was found (1957, p. 24) that transport was chiefly in the marble complex above the hard-schists. The same is true for the Sitasluspen area and to some extent for the Haukajaure area.

The last phase discerned by me is the *Raijkijokka phase*. This phase involved transport mainly toward about S85°E and S5°W. From regional strike considerations, the former could have been the main transport, provided that they were contemporaneous, which was not necessarily the case. In the north, deformation was mostly ruptural and not very penetrative, in the south, however, there was some flexuring of s-surfaces and formation of lineations.

The determinations of axial concentrations, on which these directions are founded, are subject to maximum errors of about 1° . Concentrations diverging less than 5° must be regarded as one.

The directions of transport enumerated are normalizations of axes reappearing with the same age-relationships in area after area. They may vary in direction, so that it may be difficult or impossible to assign a direction of axes to the correct phase, but it has become very obvious that there is no constant trend of direction change for any of the transport directions. Some axes change directions by, at the most, 2° . However, as variation does exist from area to area, it is important to check that what appear to be distinct populations within the areas do not get blurred into a continuum in a regional synopsis. This has been done in D1 and D2 (below).

D1 shows areal lineation maxima (dots) for all the six areas and β maxima (crosses) for all except the Pålnoviken area, where no total β diagram was prepared. Maxima that are among the 2—3 strongest of their areas are shown by the bigger signs. One may, more or less clearly, discern groups about $N83^\circ W$, $N65^\circ W$, $N52^\circ W$, $N31^\circ W$, $N17^\circ W$, $N6^\circ E$, $N25^\circ E$, ($N35^\circ E$), and $N57^\circ E$. The transverse axes coincide tolerably well with the enumerated directions of transport. D2 shows lineation and β maxima for the tectonic unit diagrams from the sub-areas of the three southernmost areas (1958). Total areal and sub-areal diagrams have not been used. Maxima that are among the 3—4 strongest are shown by bigger dots. The clusters that appear best are about $N75^\circ W$, $N49^\circ W$, $N31^\circ W$, $N23^\circ E$, and $N51^\circ E$. There seem also to be clusters about $N64^\circ W$, $N55^\circ W$, $N39^\circ W$, $N19^\circ W$, $N5^\circ E$, and $N88^\circ E$. The directions of the clusters are essentially the same as those previously enumerated, but the component dots are more dispersed than in D1. So, these two diagrams, when seen together, prove the importance of total areal diagrams for an accurate representation of the main axial trends.

There is extremely little real evidence for *en bloc* movements within the nappe complex. Practically all structures can be interpreted as due to componental movement.

It is possible that the Palnoluokta phase was not the earliest deformation phase of these areas. There could have been even more penetrative phases before, but, if so, their traces were obliterated by the Palnoluokta phase. After that, the deformation phases were of successively smaller regional importance.

According to VOGT (1942, figs. 1, 2) the general strike of pre-Cambrian structures of the Rombak—Sjangeli window is about N—S. The transports of the Palnoluokta phase cut over this strike at varying, oblique angles, with an amazing constancy of transport direction for each stage of the phase. At the beginning of the Trappsteget phase, the Caledonian nappe complex was completely penetrated by the fabric axes of the Palnoluokta phase. Nevertheless, transport during the Trappsteget phase proceeded along its own courses and imposing its own axial fabrics, with little deviation from the two main trends. The Rajikijokka phase, at last, left all the tectonic units with some folds or fractures of N—S and E—W trends. The conclusion is that fabric axes were mainly determined by directions of tectonic trans-



D1.



D2.

- D1. — Maxima from total areal diagrams. Dots=lineation maxima, crosses= β maxima. (SCHMIDT net used. Lower hemisphere. Arrow pointing N. Same things apply to D2.)
 D2. — Maxima from tectonic unit diagrams of three southernmost areas. For further explanations of both diagrams, see text.

port, and that these directions were largely independent of the structure of the basement (cf., on the other hand, LANDMARK 1949, pp. 49, 57, & 1951, p. 247. LANDMARK'S reference to WEGMANN 1935, pp. 338, 339, is hardly justified, as it is not clear that this author refers to the influence of substratum on major thrust trends).

It has been demonstrated that in these areas there were several distinct stages of deformation, that each of those discerned had its own direction of transport (a more refined technique than mine could possibly be used to distinguish phases of one and the same direction), that this direction could be virtually constant over a distance of 85 kilometres along the average tectonic strike, and that it was largely independent of the configuration of the basement and preexisting fabrics. Both of the last-mentioned factors might, however, to some extent check the local effect of a certain deformation phase.

Similar results are being obtained from an area in SW Scotland, where I have collected a very great number of fabric data. There is evidence of two major phases of deformation with different directions of transport (roughly NW and roughly S). The two resulting fabrics largely overlap in space, for the rest they dominate in different sub-areas. In the six areas so far considered, it is also a commonplace finding that a certain phase left relatively unimportant traces in one area, or sub-area or tectonic unit, but left dominant fabric in another. Whereas, generally, the probability of the total autonomy of one axial system is reduced as we consider larger and larger regions, local autonomy may be important enough. Some deflections of regional strike may be due, not to primary arching of an orogen, but to the addition of members with different strikes during the succession of differently directed movements that built the orogen system. Other swings of strike may be due to transition from $B'=a$ to $B=b$ fabric (cf. PADGET 1955, pl. 1).

For stratigraphy, it is one of the most important questions, to what extent evidence of tectonic activity can be used as indicators of contemporaneity. The question whether tectonic movements are a continuum, or local episodes, or more than local episodes, is generally answered by affirming the last alternative. To the extent that this opinion rests on stratigraphic findings, stratigraphy seems to be begging the question. Only from detailed tectonic studies can we get a valid confirmation of the more-than-local correlation of tectonic events. For the main Caledonian cycle, STILLE (1950, p. 226) distinguishes three major phases, VOGT (1928) four, and the same author (1945b) five phases, mainly from stratigraphic and lithologic considerations. In the present work, purely tectonic data are taken to prove that there were at least three deformation phases, of regional importance, one of them with three (or four) stages, the next with two stages, and the third with one (or two). So far, none of the phases can be dated geologically. Future work will have to carry the investigations on to areas where geologic dating is possible.

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References cited

- G.F.F.=Geologiska Föreningens i Stockholm Förhandlingar.
 N.G.T.=Norsk Geologisk Tidsskrift.
 N.G.U.=Norges Geologiske Undersøkelse.
 S.G.U.=Sveriges Geologiska Undersökning.
- Papers written in a Scandinavian language, and without an English or German summary, are marked with an asterisk.
- ALEVA, G. J. J. (1950) Geology and petrology of the Gabbi—Mesket region, Swedish Lapland. — Assen. (acad. diss. Amsterdam).
- ASKLUND, B. (1938) Hauptzüge der Tektonik und Stratigraphie der mittleren Kaledoniden in Schweden. — S.G.U., ser. C, no. 417.
- BACKLUND, H. G. (1935) Zur Tektonik des nordschwedischen Hochgebirges. — Geol. Rundschau, vol. 26, pp. 429—432.
- BJØRLYKKE, K. O. (1905) Det centrale Norges fjeldbygning. — N.G.U., no. 39.
- CLOOS, E. (1946) Lineation, a critical review and annotated bibliography. — Geol. Soc. Amer., Mem. 18.
- DIETRICHSON, B. (1953) Pseudotachylit fra de kaledonske skyvesoner i Jotunheimens forgårder, Gudbrandsdalen, og deres dannelsesbetingelser. — N.G.U., no. 184, pp. 23—70.

- DIETRICHSON, B. (1957) Valdressparagmitten og det såkalte gabbrokonglomerat i Sjødalen. — N.G.U., no. 200, pp. 8—41.
- DU RIETZ, T. (1943) Kvartsitskollorna i Ormsjö-Tåsjötrakten. — S.G.U., ser. C, no. 448. (*)
- FØYN, S. (1937) The Eo-Cambrian series of the Tana district, northern Norway. — N.G.T., vol. 17, pp. 65—163.
- FRÖDIN, G. (1921) Über die Geologie der zentralschwedischen Hochgebirge. — Bull. Geol. Inst. Uppsala, vol. 18, pp. 57—197.
- HAMBERG, A. (1910) Gesteine und Tektonik des Sarekgebirges nebst einem Überblick der skandinavischen Gebirgskette. — G.F.F., vol. 32, pp. 681—724.
- HÖGBOM, A. (1925) De geologiska förhållandena inom Stekenjokk—Remdalens malmtrakt. — S.G.U., ser. C, no. 329.
- HÖGBOM, A. G. (1909) Studies in the post-Silurian thrust region of Jämtland. — G.F.F., vol. 31, pp. 289—346.
- HOLMQUIST, P. J. (1900) En geologisk profil öfver fjellområdena emellan Kvikkjokk och norska kusten. I. Geotektonikens hufvuddrag. — G.F.F., vol. 22, pp. 72—104. (*)
- HOLTEDAHL, O. (1931) Additional observations on the rock formations of Finmarken, northern Norway. — N.G.T., vol. 11, pp. 241—280.
- (1938) in BAILEY, E. B., & HOLTEDAHL, O., Northwestern Europe. Caledonides. — Regionale Geologie der Erde, 2, II. Leipzig.
- (1953) Norges geologi. — N.G.U., no. 164. (*)
- KAUTSKY, F. (1940) Das Fenster von Gautojaure im Kirchspiele Arjeplog, Lappland. — G.F.F., vol. 62, pp. 121—147.
- & TEGENGREN, F. R. (1952) Die Geologie der Umgebung des Tuoddarjaure am Südrande des Sjangelifensters. — G.F.F., vol. 74, pp. 455—474.
- KAUTSKY, G. (1946) Neue Gesichtspunkte zu einigen nordskandinavischen Gebirgsproblemen. — G.F.F., vol. 68, pp. 589—602.
- (1953) Der geologische Bau des Sulitelma—Salojauregebietes in den nordskandinavischen Kaledoniden. — S.G.U., ser. C, no. 528.
- KIENOW, S. (1949) Beiträge zur Geomechanik. 1. Über Faltungsschieferung. — N. Jb. Min. Geol. Paläontol., Abt. B, vol. 90, pp. 345—378.
- KULLING, O. (1930) Studier över den kaledoniska fjällkedjans stratigrafi och tektonik inom norra delen av svenska Lappland. — G.F.F., vol. 52, pp. 647—673.
- (1933) Bergbyggnaden inom Björkvattnet—Virisen-området i Västerbottensfjällens centrala del. — G.F.F., vol. 55, pp. 167—422.
- (1953) Fjällkedjans berggrund. Bedrock of the Caledonian mountain range. — Atlas över Sverige, Geology, 7—8, Pre-Quaternary rocks.
- (1955) Den kaledoniska fjällkedjans berggrund inom Västerbottens län. — S.G.U., ser. Ca, no. 37, pp. 101—296.
- KVALE, A. (1945) Petrofabric analysis of a quartzite from the Bergsdalen quadrangle, western Norway. — N.G.T., vol. 25, 1946, pp. 193—215.
- (1948) Petrologic and structural studies in the Bergsdalen quadrangle, western Norway. II. Structural geology. — Bergens Mus. Årb. 1946 & 1947, Naturv. rekke, no. 1.
- (1953) Linear structures and their relation to movement in the Caledonides of Scandinavia and Scotland. — Quart. J. Geol. Soc., vol. 109, pp. 51—73.
- LANDMARK, K. (1949) Geologiske undersøkelser Luster—Bøverdalen. — Univ. Bergen Årb., 1948, Naturv. rekké, no. 1.
- (1951) Tverrfolding i den kaledonske fjellkjede. — N.G.T., vol. 29, pp. 241—247. (*)
- LINDSTRÖM, M. (1955) Structural geology of a small area in the Caledonides of arctic Sweden. — Lunds Univ. Årsskr., N.F., Avd. 2, vol. 51, no. 15.
- (1956) A tectonic study of Mt. Nuolja, Swedish Lapland. — G.F.F., vol. 77, 1955, pp. 557—566.

- LINDSTRÖM, M. (1957) Tectonics of the area between Mt. Keron and Lake Allesjaure in the Caledonides of Swedish Lapland. — *Lunds Univ. Årsskr., N.F., Avd. 2*, vol. 53, no. 11.
- (1958) Tectonic transports in three small areas in the Caledonides of Swedish Lapland. — *Lunds Univ. Årsskr., N.F., Avd. 2*, vol. 54, no. 3.
- MARKLUND, N. (1949) A study in a Caledonian mayor thrust plane. — *Bull. Geol. Inst. Uppsala*, vol. 34, pp. 205—222.
- OFTEDAHL, CHR. (1948) Deformation of quartz conglomerates in central Norway. — *J. Geol.*, vol. 56, pp. 476—487.
- PADGET, P. (1955) The geology of the Caledonides in the Birtavarre region, Troms, northern Norway. — *N.G.U.*, no. 192.
- REUSCH, H. (1888) Bømmeløen og Karmøen med omgivelser. — Kristiania, Ed. N.G.U.
- SANDER, BR. (1948 & 1950) Einführung in die Gefügekunde der geologischen Körper. I & II. — Wien, Springer Verl.
- SCHMIDT, W. (1932) Tektonik und Verformungslehre. — Berlin, Borntraeger Verl.
- STILLE, H. (1950) Die kaledonische Faltung Mitteleuropas im Bilde des gesamteuropäischen. — *Z. Deutsch. Geol. Ges.*, vol. 100, 1948, pp. 223—266.
- STØRMER, L. (1933) Spor av kaledonisk overskyvning i Nordmarka. — *N.G.T.*, vol. 13, pp. 116—128.
- STRAND, T. (1938) Nordre Etnedal. Beskrivelse til det geologiske gradteigskart. — *N.G.U.*, no. 152.
- (1945) Structural petrology of the Bygdin conglomerate. — *N.G.T.*, vol. 24, pp. 14—31.
- STRÖMBERG, A. (1955) Zum Gebirgsbau der Skanden im mittleren Härjedalen. — *Bull. Geol. Inst. Uppsala*, vol. 35, pp. 199—245.
- TÖRNEBOHM, A. E. (1888) Om fjällproblemet. — *G.F.F.*, vol. 10, pp. 328—336 (*)
- (1896) Grunddragen af det centrala Skandinaviens bergbyggnad. — *Kungl. Sv. Vet.-Akad. Handl.*, vol. 28, no. 5.
- VOGT, TH. (1927) Sulitelmafeltets geologi og petrografi. — *N.G.U.*, no. 121.
- (1928) Den norske fjellkjedes revolusjons-historie. — *N.G.T.*, vol. 10, pp. 97—115. (*)
- (1942) Trekk av Narvik—Ofoten-traktens geologi. — *N.G.T.*, vol. 21, 1941, pp. 198—213. (*)
- (1945a) Fjellkjedens flytestrukturer og malmforekomstene. I. Nord-Rana grubefelt. — *Kong. Nor. Vid. Selsk. Forhandl.*, vol. 17, pp. 118—121. Trondhjem.
- (1945b) The geology of part of the Hølanda—Horg district, a type area in the Trondheim region. *N.G.T.*, vol. 25, pp. 449—528.
- WEGMANN, C. E. (1935) Zur Deutung der Migmatite. — *Geol. Rundschau*, vol. 26, pp. 305—350.
- WERENSKIOLD, W. (1911) Søndre Fron. Fjeldbygningen inden rektangelkartet Søndre Frons omraade. — *N.G.U.*, no. 60.

